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NOTE ON THE PRESSURE DISTRIBUTION OVER THE HULL OF  
ELONGATED AIRSHIPS WITH CIRCULAR CROSS SECTION.

By Max M. Munk,  
National Advisory Committee for Aeronautics.

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ELONGATED AIRSHIPS WITH CIRCULAR CROSS SECTION.

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Summary

This note, prepared for the National Advisory Committee for Aeronautics, contains the demonstration that the pressure around the circular cross section of an elongated airship, plotted against the diameter of symmetry, can be expected to be represented by a straight line.

Reference

Lamb, "Hydrodynamics."

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An elongated airship, when flying in pitch, yaw, or when turning, experiences lateral air forces, produced by pressure differences at different points of each cross section. If this section is circular, the air being supposed to be a perfect gas, this pressure distribution approaches one described by a very simple law with increasing elongation ratio of the hull. The knowledge of this law is of use for the airship designer when representing or interpreting pressure distribution tests with

airships or airship models. Its demonstration is the subject of this note.

It rests on the fact that with very elongated airships the transverse component of the airflow around circular cross sections is practically identical with the two-dimensional flow around a circular cylinder. Furthermore, the velocity of flight  $V$  is large when compared with the velocities produced by the motion of the ship in the surrounding air, as the angle of pitch or yaw  $\alpha$ , is supposed to be small. Now, the pressure, according to Bernouilli's law, is proportional to the (negative) square of the air velocity relative to the ship, when measured from a suitable standard, and hence is proportional to  $(V + v)^2 + w^2$ , where  $v$  denotes the velocity component near the surface parallel to the meridians and  $w$  that along the parallels of latitude. When neglecting the squares of  $v$  and  $w$ , and omitting the term  $V^2$  as only giving rise to a constant pressure, there remains the one term

$$2 v V \quad (1)$$

The air pressure, when measured from a suitable standard, is therefore equal to

$$V v \rho \quad (2)$$

Now let  $\Phi$  be the potential of the flow and hence let

$$v = \frac{\partial \Phi}{\partial z} \quad (3)$$

where  $z$  is the coordinate parallel to the axis of the ship.

The potential  $\Phi$  at all cross sections is supposed to be identical with that of the two-dimensional flow around the circular cylinder with the diameter of the hull at that section, say  $2r$ , and with the lateral velocity of the cylinder  $V \sin \alpha$ , (where  $\alpha$  denotes the angle of pitch or yaw). Hence, according to the reference, it is

$$\Phi = V \sin \alpha \cos \varphi \frac{a^2}{r} \quad (4)$$

where  $\varphi$  and  $a$  are the polar coordinates of the plane,  $a = 0$  being the center of the circle. At the points of the surface,  $a = r$  and hence  $\Phi = V \sin \alpha \cos \varphi r$ .

According to equation (2), the longitudinal velocity is then

$$v = \frac{\partial \Phi}{\partial z} = V \sin \alpha \cos \varphi \frac{dr}{dz} \quad (5)$$

By substituting (5) into (1) the pressure distribution results finally

$$p = V^2 \frac{\rho}{2} 2 \sin \alpha \cos \varphi \frac{dr}{dz} \quad (6)$$

At one particular cross section, and under constant conditions of flight, all terms of (6) are constant except  $\cos \varphi$ . This cosine is proportional to the distance of the point of the surface from that plane through the axis of the ship which is a plane of symmetry with respect to the airflow produced in pitch or yaw. Hence the air pressure, when plotted over the diameter of symmetry, gives a straight line.

This straight line does not pass through the center of the

cross section, even when the pressure is measured from a suitable standard, as the neglected squares of  $w$  give rise to a constant additional pressure.

The same arguments can be used for a flight along a circular path. The same straight line appears then too.

With actual ships and finite elongation the curve described will not come out quite straight, but at least it will be approximately so over the greatest portion of the length. This kind of plotting will give smoother curves and more regular ones than the plotting of the pressure against the angle  $\varphi$ .

It can further be concluded from the investigation finished and in particular from equation (6), that the mean pressure

$$P_m = \frac{1}{2\pi} \int_0^{2\pi} p \, d\varphi$$

should approximately be independent of any small pitch or yaw.